STUDY OF MECHANICAL BEHAVIOR OF CARBON FIBER REINFORCED COMPOSITES

SHORT SYNOPSIS

Submitted in fulfillment of the requirement of the degree of

DOCTOR OF PHILOSOPHY

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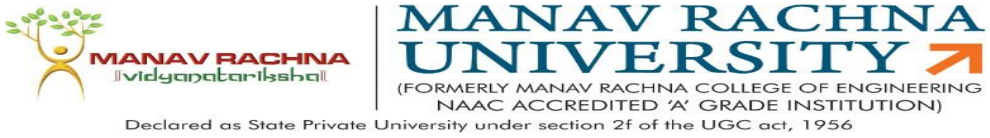
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DECLARATION BY THE SCHOLAR

I hereby declare that the Short Synopsis "**Study of Mechanical Behavior of Carbon Fiber Reinforced Composites**" being submitted in partial fulfillment of the requirement for the degree of Doctor of Philosophy in department of **Mechanical Engineering** under Faculty of Engineering of **Manav Rachna University, Faridabad** during the academic year **2018**.

It is a bona-fide record of original work carried out under the supervision of **Dr. M.R.Tyagi** has not been submitted in full or part to any other university or institute for degree or diploma. Further, it is certified that Short Synopsis is within the plagiarism limit and copy of the same is attached as per University norms.

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Proposed Title of Thesis / Research

“Study of Mechanical Behavior of Carbon Fiber Reinforced Composites”.

Comprehensive Rationale of Present Research Work

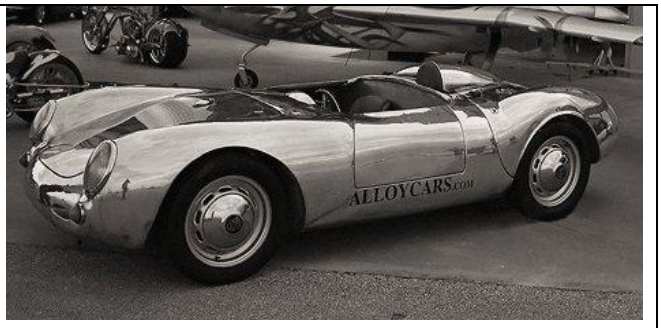
Design, analysis and development are not a destination but these are journey of a product. Product can be of any field like aerospace, railway, marine, automobile, medical, civil, electrical, electronics, sports, etc. These all products have some material like mild steel, plastics, aluminum, copper, brass, stainless steel, rubber, glass, wood, leather, cast iron, and so many. Continuous development is going on these conventional materials. Initially we use aesthetic parts of steel sheets and some other conventional materials. The most disadvantage of these materials is that they are very heavy. Production of those conventional materials also required heavy machinery and that effects the environment very badly. Using those products also create bad effect on the environment. The environment is the most important for the survival of all living organisms. At least, developed countries understood the importance of the environment. Therefore, development is going on how to reduce the weight of a product.

Early Aeroplane [1]

Early Automobile [2]

Aesthetic and other parts were replaced with aluminum alloy. Because it is lighter and stronger than conventional material and can perform the much better functions.

Aluminum Body Aeroplane [3]



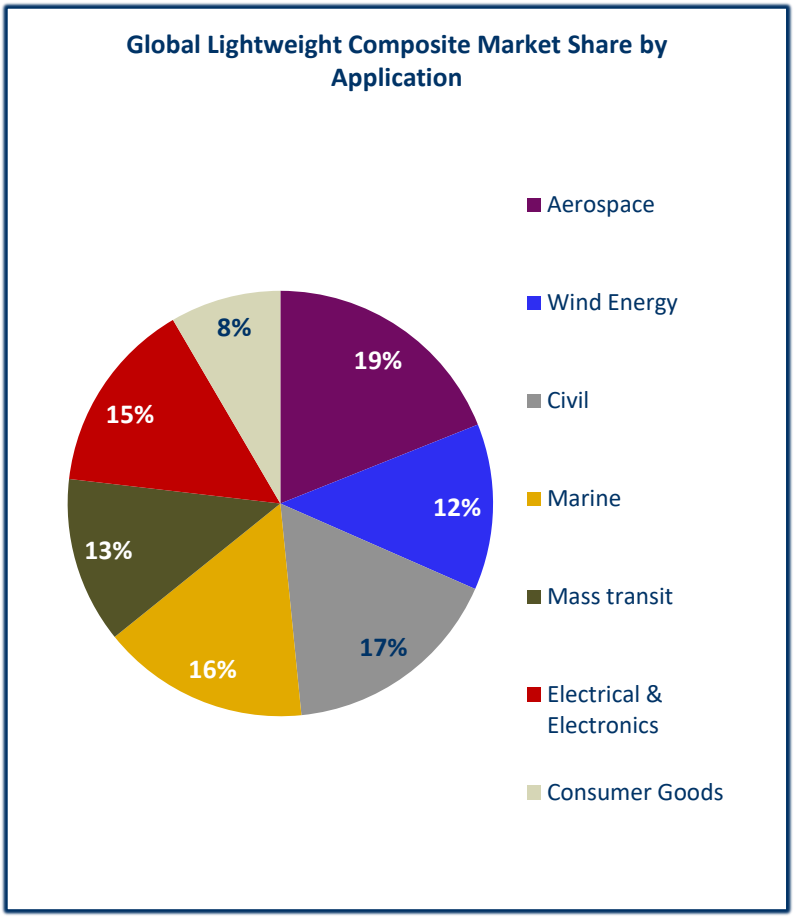
Aluminum Body Car [4]

Developed countries already gone through the phase of steel and then aluminum. Now they are using still lighter and stronger material i.e. composites. It's not possible to completely replace the conventional materials. Conventional materials are still used in the products. But wherever possible, they are replacing conventional material with lighter and stronger material.

Aerospace [5]	Railway [6]
Wind Energy [7]	Construction [8]
Marine [9]	Automobile [10]
Music Instruments [11]	Sports [12]

In India, still we are using only conventional material and don't care of the environment. No original equipment manufacturers are using any composites except few. Modi government announced to replace the all petrol/diesel vehicle by 2030 because they are heavy and effect the environment adversely [13].

5 g of CO_2/km is reduce if the weight of any vehicle reduce by 50 kg. In this way, fuel economy increases by 2% [14]. Light weight and strong composites are the today's necessity for the survival of all living organism on the Earth. Percentage wise application of composite is shown here:



[15]

Conclusion from Comprehensive Rationale of Present Research Work

It is just starting of growth of the Carbon Fiber Reinforced Composites (CFRC). Lot milestone to be achieved in this field. The basic reason to research in this field are as follows:

- Lighter Weight
- Stronger than conventional material
- Useful for the environment
- Sustainable point to be add.
- Researcher are still working on application of Carbon Fiber Reinforced Composites.

Introduction

Extensive research is being conducted to find alternatives to steel and other, heavier metals. As the weight reduces, fuel efficiency increases and their maintenance also becomes ease. Composite materials are very good alternative sources for this purpose.

Composites are manufactured when we combined different materials. They have unique properties other than the parental materials. We can easily identified the different materials as they don't mix up each other [16].

Natural Composites

Composites are also available in nature also. Most common natural composites is wood. There are two materials i.e. cellulose fibers and lignin. Cellulose and lignin are polymer. Bamboo is also a composite. It is lighter and stronger than wood. Its compressive strength is very good [16].

Wood and Bamboo as Composites

Composites are also available in living organisms like human and animals. Bones of living organism are also one type of composites. It is made up of hydroxyapatite and collagen. Hydroxyapatite is calcium phosphate and it is brittle material. Collagen is protein and it is soft and flexible material. Bones must be light and strong [16].

Early Composites

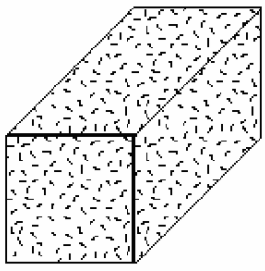
Composites are not discovered recently but it is used by people thousand years ago. They used it to make their houses. They used to mix the mud with the straw. Mud has good compressive strength but tensile strength is not good. Straw has good tensile strength but compressive strength is not good. By combining these two, we have good compressive and tensile strength. That's why earlier

people use it. They use it in floor and walls. After sometime, they started to manufacture bricks from this composite [16].

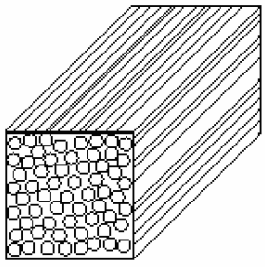
Mud and Straw as Composites

Binder and Reinforcement

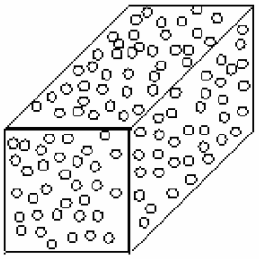
There are mainly two components in CFRC. These are binder/matrix/host and reinforcement. Different types of binders are epoxy, phenolic polyamide resins and polyester. These are the thermoset resins. Epoxy resins are the most common. Different types of reinforcement are glass fiber and carbon fiber. Development started from glass fiber and still it is used because their cost is not high. But they are heavy. Now a days CFRC is in demand because of its light weight and strength. But it is costlier than glass fiber. CFRC is used where cost is not the factor like aerospace, wind turbine, supercars, etc. Reinforcement can be in the form of short-fibre, long-fibre, particulate and flake as shown below.



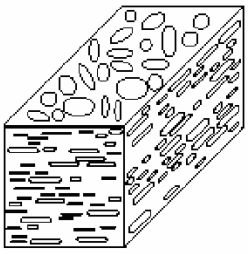
Short-Fibre Reinforced composites



Long-Fibre Reinforced composites



Particulate composites



Flake composites

Types of Reinforce composites

Examples of Modern Composites

Fiber glass was the first modern composite material. It is composite of glass fibers and plastics. Glass fibers are known as reinforcements. These are most versatile and predominant fibers used in the polymer industry. These are very strong and it breaks if bent sharply. They have more than 50% silica. Various application of FRP are building panels, boat hulls, car bodies and sports equipment. Purpose of plastic is to hold the reinforcements and protects them from various forces [16].

Now a days, carbon fibers are used instead of glass fibers. CFRC are more expensive but lighter and stronger than fiberglass. Various applications are shown above [16].

Less is more with High-Performance Materials

One line is famous with composites is that "less is more with high-performance materials". Because composites are less in weight but higher in strength [14].

Properties of CFRC

CFRC is 5 times stronger than steel, 2 times stiffer, and about Two-Third times less in weight.

- It has low thermal expansion.
- It is a good conductor of electricity.
- It can wear a high resistance.

Advantage of CFRC

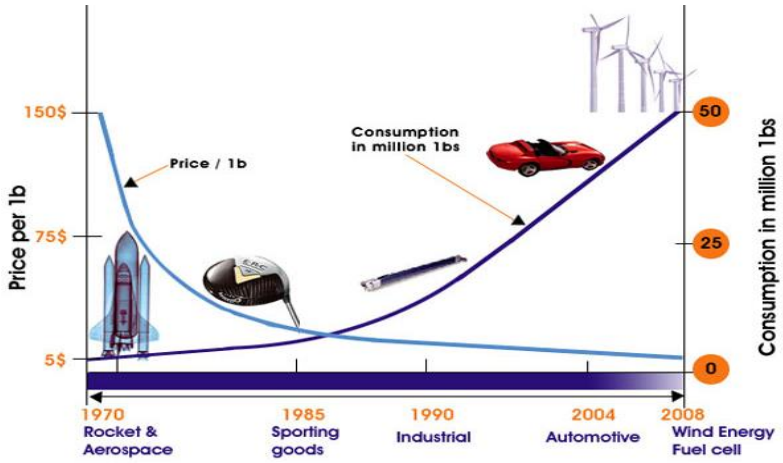
- It has long working life.
- Its density is less than conventional material.
- It is insensitive to change in temperature.
- Its compressive strength is greater than all the reinforcing material.

Limitations of CFRC

- It is very expensive.
- Fiber alignment is critical issue.

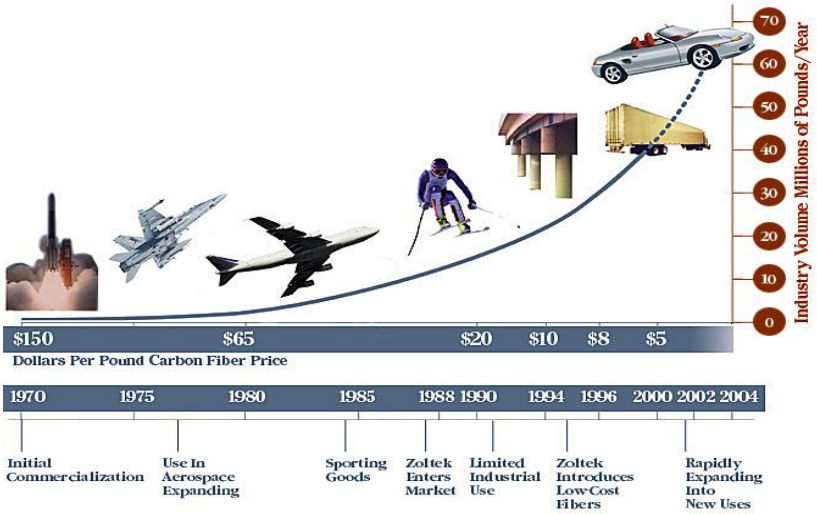
Business of CFRC

Business of CFRC is increasing day by day therefore it's pricing is also reducing. It's applications are also increasing from rocket to daily uses products as shown above. Demand of CFRC is increasing in windmill industry, marine, railway, aerospace, automotive, sports, construction, etc. The average growth rate is 12% from last 23 years [17].



Trends and Forecast in Carbon Fiber Shipment [17]

Journey of CFRC started from the industry of aerospace. Then its application increases in sports because of the requirement of light and strong products. After that its application increases in construction because of rust proof property and easy to take the shape of required structure. Now its demand is increasing in commercial and automotive industry. Due to the properties of CFRC, its demand is endless and will continue to grow in future also [18].



Market and Price [18]

Review of Literature

CFRC are the future of material. Literature review is must to know the present situation of CFRC in the various industry. We have did the review of literature and kept those in different vertical like modeling and analysis, composition, application, etc. Review of literature is as follows:

Modeling, Analysis and Testing

Weaver P. and Daynes S. [25] studied analysis of metal hybrid of Carbon Fiber Reinforced Plastic using different techniques. First it is analytical then FEM and last was experimental method. Thermal analysis also conducted with thermal loads and boundary conditions.

Wilckens D. et al [26] in 2013, analyzed the CFRP panels for the bucking and post buckling behavior with experimental and virtual analysis. Different types of load were applied like shear, compressive and combination. CFRP panels were experimentally tested for collapsing with shear and compressive load. Shell model is developed in ABAQUS software. Finally comparative analysis was done for experimental and virtual analysis.

Charles Mbohwa and Mushiri Tawanda [27] in 2015, calculated the contact stress in spur by FEA in ANSYS software. Maximum contact stress were calculated by Hertz equation. Material used for the product was grey cast iron and steel. Results of theoretical and virtual analysis were comparable.

Kiekbusch T. et al [28] in 2011, different pairs of spur gear generated and torsional mesh stiffness calculated with FEM in ANSYS software in 2D and 3D that can be used in gearboxes. Teeth, contact and body were the three main components to determine the overall stiffness for variety of gears. Results of 2D, 3D and theoretical were compared.

Nikolic V. et al [29] in 2011, developed a gear transmission dynamic model for the stress and strain analysis. Degree of freedom was four. Virtual analysis considered nonlinear finite element method.

Do T. et al [30] in 2014, contact forces and characteristics were studied during meshing of straight beveloid gears with fully elastic multibody approach. The comparative study conducted of the gear by FEM and fully elastic multibody system.

Trobentar B. et al [31] in 2015, presented an article describes an investigation regarding the deflection behavior of polymeric gear transmission using FEM in ABAQUS software and the numerical results were then compared with the analytical results. Young's material model and the hyper elastic Marlow model was used to determine gear deflection behavior. Numerical analyses also indicated that an appropriate non-linear material model should be considered in the case of higher contact forces, and consequently large deflections.

Kumar S. et al [32] in 2016, developed the model of transmitting power gear assembly on CAD software and FEM based structural behavior of different material were studied. Total deformation, von mises stress and natural frequencies at various mode were determine using ANSYS software.

Myler P. and Farooq U. [33] in 2015, studied the buckling of carbon fiber reinforce laminated composite for aerospace industry with FEM in ABAQUS software. Group equipment collisions and drop tool impacts were the major draw backs observed. Higher factor of safety is considered because safety of human lives is the primary concern. Virtual testing is preferred over physical testing because that consumes time and resources and generate only repeated data.

Chuku E. et al [34] in 2014, stress and strain analysis of helical gears conducted by developing a visual basic program. American Gear Manufacturer's Association referred for the design parameters of gear.

Lei S. and Zheng C. [37] in 2009, developed the high-pressure vessel for hydrogen storage. Inner layer of the vessel was of Aluminum and outer layer of CFRC i.e. anisotropic. Load is applied in two ways i.e. internal pressure in hoop directional only and internal pressure on axial direction only. Hybrid vessel is obtained which can bear the stress and strain.

Rakesh P. et al [39] in 2011, composites are used in many industries from sports to aerospace. 3D CAD model developed of drill and virtual analysis of drilling was done in ABAQUS software. Experimental behavior of drilling was comparable with virtual data.

Russell B. et al [48] in 2016, manufactured the sandwich beams from CFRP with sheets like square honeycomb structure. Product hold at the ends and different bending load applied at various location. Results compared from theoretical and FE model data.

Botkin M. [49] in 2000, developed the roof of a car with CFRP. 3D Modeling and FE analysis were conducted with shell elements. Roof obtained was 71% lighter than conventional material.

Modeling, Analysis, Manufacturing and Testing

Robert F. et al [19] in 2012, designed the composite gears and tested at NASA. It was the hybrid of composite and metal. It was 20% lighter than all-steel gear. They compared the results of all-steel gear and hybrid gear. The main problem faced by them was of concentricity. The hybrid gear completed the 300 million cycles at 10000 rpm and 553 in.lb torque. The test also conducted for vibration modes. Results were good without sacrificing the strength.

Bussadori B. et al [24] focused on the numerical crashworthiness design of CFRP structures and two different numerical models were developed in order to reproduce experimental crush test on CFRP tube previously made. The influence of several different parameters on the final results was analyzed.

Takahashi Y. et al [63] in 2015, developed and manufactured the press tool for the stamping of CFRP with heating it. The process is also performed in FEM with ABAQUS software.

Modeling, Analysis, Composition, Manufacturing and Testing

Gasparin A. et al [20] in 2012, established the material of a worm gear to be used in automotive with seven different polyamide (PA). The mechanical properties checked during the process were impact resistance, Young's modulus and tensile strength. They also checked the moisture absorption. Before performing the test on rig test, FEA was also checked.

Mechanical Properties

Kalamkarov A. et al [21] in 1996, described the method for the development of mechanical properties i.e. high stiffness from CFRP. Analysis is developed with the help of design parameters. The design problem is formulated and solved for a maximum strength of CFRP.

Enetanya N. and Ihueze C. [38] in 2012, established GRP composites structures of automobile for better mechanical properties like crashworthiness, compressive and buckling strength. Compressive strength was obtained by Monsanto tensometer. Area under the stress-strain curve was evaluated with Gauss-Legendre two point rule.

Afshar A. et al [46] in 2016, investigated the FRP in military marine that are exposed to cyclic loading, moisture and ultraviolet radiation. Structural integrity and mechanical properties are degraded because of these elements.

Shaohua Chen and Yin Yao (2016), studied the surface roughness of CFRP in longitudinal direction. CFRP surfaces have many grooves and micro ridges influence its behavior.

Jeong T. and Ueda M. [51] in 2016, studied the CFRP with longitudinal compressive failure using multiple-fiber model. Developed the rectangular beam and bending test performed.

Muhammed O. et al [52] in 2011, demonstrated squeeze casting with different parameters. Round specimen developed and tensile test performed on UTM.

Gouda P. et al [53] in 2011, developed the CFRP specimen to conduct the tensile test on UTM. 3D Model and FE analysis also performed.

Wua L. et al [54] in 2011, experimented the sandwich structure of CFRP to test the tensile strength and low-velocity impact characteristics. 3D Model and FE analysis developed in ABAQUS to compare the results.

Lacassea P. et al [55] in 2008, performed the physical testing on CFRP by tensile and bending test. Fracture toughness improved by 50%.

Composition

Brighenti R. [22] in 2004, analysis the behavior of CFRP through a physical-based approach. An imperfect bound is considered between the matrix and fibers with elasto-plastic behavior. Axial strength of fibers is much better than bending. A certain amount of sliding is assumed at the matrix-fiber interface. The fibers are assumed to have only axial stiffness with relative matrix-fiber displacements orthogonal to the fibers axis.

Paiva J. et al [23] in 2006, developed different laminate by different matrix that contains a curing agent. Tensile tests were performed to evaluate the samples. Highest tensile strength was of F584/Plain Weave. Highest modulus of rigidity was of 8HS (Harness Satin). The results emphasizes the importance of the adequate combination of matrix and reinforcement for proper composites.

Hwang J. et al [35] in 2014, developed the composite bars as conventional material have issues of weight and corrosion. These were used for the concrete structures. Lower elastic modulus is the material property of FRP bars observed but have brittleness. Therefore, FRP Hybrid bars

developed with steel wires with different diameters and in different proportions instead of carbon fibers.

Prasad T. and Ramesh C. [36] in 2009, studied the carbon and graphite fiber by liquid metallurgy route and investigated for the room temperature friction and wear properties. Pin-on-disk machine used for conducting the test of friction and wear with different parameters like speed and load.

Rials T. and Baker D. [42] in 2013, developed the CFRP with lignin to reduce the weight so that fuel consumption can be reduced. Limitation of this CFRP was that lignin should be pure.

Application

Alsharie H. (40) in 2015, studied the about the conventional floors that can be replaced by non-conventional material i.e. fiber reinforcement. Life of the floor can be increased by efficient design. Quantity of raw material, steel and labor cost can be reduced by adapting non-conventional material.

Chou H. et al [45] in 2016, developed and tested the pressure vessels of CFRP with viscoelastic properties under the loading condition as steady pressures. Specimen of pressure vessel developed with fiber direction as unidirectional.

Zhupanska O. and Sierakowski R. [50] in 2011, studied that electric current in CFRP increase its impact load and impact damage. But as the current increases heat induced in CFRP which makes it soft.

Wua L. et al [56] in 2010, fabricated the CFRP truss structure and investigated the crushing response. FE model also developed the virtual analysis and results compared.

Guan Z. et al [57] in 2011, developed the core plate sandwich of CFRP by compression molding and check the results by three methods i.e. numerical, theoretical and experimental. Results obtained were comparable.

Narmashiri K. et al [58] in 2012, developed the I-beams with CFRP material and perform the various test with modeling and experimental. FE analysis performed in ANSYS software. Results were comparable.

Wang S. et al [59] in 2010, modeled the CFRP laminates in ABAQUS software and check with low-velocity impact characteristics and residual tensile strength.

Zheng K. et al [60] in 2016, developed the method to detect the defect in CFRP by pulse thermography.

Yin S. et al [61] in 2011, experimented the CFRP structure by filling it with silicon because it have enormous space to improve the energy absorption capacity and mechanical property.

Galloway M. et al [62] in 2009, manufactured the vehicle part by cured with X-ray beams. The product by this method have high quality class A surface. X-ray beam removes the internal stress developed in the process.

Yin C. and Tail C. [64] in 2014, developed and manufactured the frame of a bike with CFRP and performed physical and virtual test to check the performance.

Defeng Z. et al [65] in 2013, constructed the building pillars for the purpose of civil and checked the condition in earthquake. FEM modeled also developed.

Machining

Vorm T. et al [41] in 1983, examined cutting of CFRP in both direction i.e. parallel and perpendicular. The investigation techniques used were a new chip preparation and quick-stop experiment. Machined surface and types and quality of chips were the two parameters discussed. Parameters which measured were forces in perpendicular and parallel orientation with tool wear.

Panneerselvam K. and Shunmugesh K. [44] in 2016, machined the CFRP both in transverse and longitudinal direction with optimize process parameters like feed rate, cutting tool material and speed. Parameters like Torque and thrust force were observed using different instruments during machining. Particle Swarm Optimization – Gravitational Search Algorithm (PSO-GSA) and Genetic Algorithm (GA) techniques were adapted to optimize the process.

3D Printing

Matsuzaki R. et al [43] in 2016, conducted the experiment for the 3D printing of the CFRP by deposition modelling. Several specimen printed with tensile test in longitudinal direction.

Conclusions from Literature Review

From the literature review, it can be concluded that CFRCs are used in various applications since 1970. They have shown good mechanical and other properties. From the literature, it is seen that the researchers have keen interest in the study of CFRCs. However, there are still many challenges for their general use as a replacement of current conventional engineering materials. This is a subject of keen interest to find out correlation between the composition of CFRCs and their relation to physical properties and engineering performance behavior. In view of this, it is decided to pursue the studies on finding such correlation and examine the feasibility of their use as a much lighter and stronger substitute for currently used engineering materials.

Objectives of the present work

Objectives of the present work are as follows:

- To study the mechanical properties of CFRC with different composition like filament diameter, fiber orientation, types of matrix, etc.
- Application of CFRC in Engineering Component and check its feasibility for their use in mechanical system by testing them against relevant performance parameters.

Hypothesis

Mechanical products are heavy due to conventional material. So our hypothesis is reduce the weight of the mechanical products without compromising the specified requirements by using CFRC. The basic hypothesis is that the mechanical properties of CFRCs can be substantially influenced by varying their composition.

Work Plan and Methodology

Work plan and methodology of our research will be as follows:

S.No.	Activity
1	Literature review of CFRC.
2	Analysis of the specimen with conventional material as per the standard of ASTM.
3	Manufacturing of the specimen with conventional material.
4	Experimental Testing in UTM of the manufactured specimen with conventional material.
5	Compare the results of Analysis and Experimental Testing.
6	Repeat the 2, 3, 4 and 5 steps for developed composite material.
7	Virtual and physical testing of selected engineering component.
8	**Theoretical Analysis** of selected engineering Component.
9	Compare the results of FEA, Experimental Testing and Theoretical Analysis.
10	Thesis preparation and submission.

Proposed Time Frame (Gantt Chart)

Semester		I	II	III	IV	V	VI	VII
Time Frame		Jan-June 2016	July-Dec 2016	Jan-June 2017	July-Dec 2017	Jan-June 2018	July-Dec 2018	Jan-June 2019
Activity	General Course Work							
	Synopsis Presentation							
	Review of Literature							
	Paper Publication							
	Area Specific Course Work							
	ANSYS Learning from EDX							
	Submission of Synopsis							
	Virtual and Experimental Testing of the specimen from conventional and non-conventional material.							
	Paper Publication							
	Virtual and Experimental Testing of the selected engineering component.							
	Paper Publication							
	Thesis Preparation							
	Thesis Submission							

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Ref. No.: MRU/PhD/SYN/2016/017 Date: January 20, 2018

NAME: Mr. JOGINDER SINGH

SUBJECT: SYNOPSIS APPROVAL

We are pleased to inform you that your research proposal entitled "**Study of Mechanical Behavior of Carbon Fiber Reinforced Composites"** under the supervision of **Prof. (Dr) M. R. Tyagi** has been approved by University. You are entitled to present pre PhD seminar before DRC. Your date of registration at University is **Jan 18, 2016**. You are directed to submit your progress reports and re-registration forms through proper channel for every semester till the submission of Thesis.

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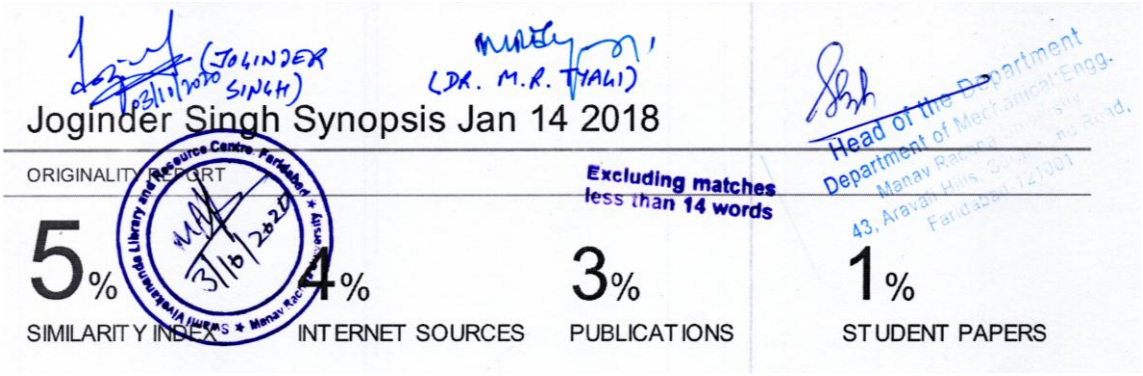

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